Physiological and psychological effects of infrasound on humans

Møller, Henrik

Published in:
Journal of Low Frequency Noise, Vibration and Active Control

Publication date:
1984

Physiological and Psychological Effects of Infrasound on Humans.

Henrik Møller.
Institute of Electronic Systems, Aalborg University, Strandvejen 19, DK-9000 Aalborg, Denmark.
(Received 1 February 1984)

ABSTRACT

Sixteen subjects were exposed for three hours to inaudible infrasound, audible infrasound, traffic noise and a quiet control condition, while they performed various psychological tasks. Some cardiovascular and hearing parameters were recorded and after the experiments the subjects answered a questionnaire concerning their experiences during the noise exposure.

The most conspicuous effect of infrasound was a high rating of annoyance and a feeling of pressure on the ear at less than 20 dB above the threshold of hearing. No influence on the cardiovascular system was seen and the performance only deteriorated in one of nine tasks. Infrasound below the threshold had no effect.

It is concluded that a better knowledge of the hearing at low frequencies is required, the most urgent being an extension downward in frequency of existing curves of equal loudness and equal annoyance.

1. INTRODUCTION

Infrasound is defined as acoustic waves with frequencies below 20 Hz, the frequency that is generally accepted as the lower limit of the normal hearing range. However, it has been shown that the human ear is able to detect infrasound when the sound pressure is sufficiently high, and threshold values at different frequencies have been determined (Refs. 1,2,3,4,5).

Researchers and environmental authorities have also been interested in – and worried about – possible extra-auditory effects of infrasound. There is a widespread opinion that infrasound may disturb human body functions and influence the performance of humans. Frequently mentioned effects are; changes in blood pressure, heart rate and respiration, disturbance of equilibrium, changes in production of stress-hormones and secretion of gastric juice, increased reaction time and decreased performance in vigilance tasks.

The experimental evidence is, however, rather sparse. Few experiments have been carried out and the results of these are not consistent. Furthermore, most of the studies have used only relatively short exposure times (2-60 minutes). In particular, there is a lack of information about the long term effects of the most common infrasound, i.e. at levels below and just above the hearing threshold.

In the present investigation an exposure time of three hours was chosen and the exposures were to infrasound just below and slightly above the hearing threshold. Also, a traffic noise condition was included in order to make it possible to compare the effects of infrasound with those of a familiar sound. Recordings were made of performance in nine different tasks, some cardiovascular and hearing parameters, and the subject's own experiences as expressed through a questionnaire.

The investigation described in this paper was finished in 1980, and some of the results have already been published (Refs. 6,7). However this is the first complete presentation.

2. METHOD

2.1 Subjects

Sixteen paid volunteers participated in the experiments, eight men and eight women. Fifteen were between 20 and 28 and one was 43. The subjects were all healthy and had normal hearing within ±20 dB at the octave frequencies from 125 Hz to 8 kHz.

2.2 Test room

The experiments were carried out in a 16 cubic metre infrasound test chamber, where the infrasound was produced by 16 electrodynamic loudspeakers. The frequency response of the generating system was flat from below 1 Hz to nearly 30 Hz and the maximum obtainable sound pressure level was 125 dB rms. The harmonic distortion was kept very low to ensure that the exposure was purely infrasonic. The vibration levels of the walls and the floor were also low enough to avoid any effects from them. A detailed description of the room has already been published (Ref. 8).

The test chamber was equipped with a ventilating system which gave sufficient fresh air for the subjects (60 cubic metres per hour). However, air conditioning was not possible since the air was simply taken from the surrounding laboratory. Air temperature, humidity of the air and atmospheric pressure were recorded during the experiments. Some fluctuations did occur, but they were not systematically related to any of the sound conditions. The ranges were: temperature; 20-24^{o}C, relative humidity; 35-55%, atmospheric pressure; 98.1-103.8 kPa.

2.3 Sound conditions

Four sound conditions were used: infrasound at two intensity levels, traffic noise and a quiet control condition.

Infrasound (Sound conditions C and D). It is reasonable to expect possible effects to be dependent on the frequency and amplitude of the infrasound. Some investigations have even suggested that certain pure tones are especially dangerous (Refs. 9,10). There is, however, some disagreement about the frequency of these tones and it must be admitted that the scientific evidence as to particularly hazardous frequencies is rather sparse.

Random noise in the infrasonic frequency range was chosen. This kind of noise includes all frequencies and thus also all the above mentioned "particularly hazardous" frequencies. The origin of the noise signal was frequency-limited white noise, but if this signal had been used directly, then the upper part of the spectrum (frequencies near 20 Hz) would have been very loud compared to the lower frequencies due to the slope of the hearing threshold curve. An attempt was therefore made to make the low and high frequencies equally audible by introducing a compensating filter which shaped the spectrum of the sound to correspond to the hearing threshold curve. According to a one-third octave analysis this was effective from approximately 6.3 Hz to 31.5 Hz, thus covering the part of the infrasonic range that is most likely to have some effect, and also giving a minor overlap into the audio region.

A pilot study with a few subjects served to determine the two levels of this frequency-shaped infrasound to be used in the main experiment. The lower level (i.e. Sound Condition C) was chosen as the highest possible level where the signal was still inaudible. This level was included since there is concern about the possibility that inaudible acoustic waves may affect people. The higher level (i.e. Sound condition D) was chosen to be 20 dB above the lower level, and in the pilot study it was characterized as loud and annoying. Spectra of the sounds are given in Figure 1.

Traffic noise (Sound condition B). This was recorded in a main street in Aalborg and reproduced by ordinary high fidelity equipment. The playback level chosen resulted in an A-weighted equivalent continuous level of 70.9 dB(A). The fluctuating properties of the noise are expressed by the following statistical measures: L_{10} = 74.3 dB(A), L_{50} = 69.3 dB(A), L_{90} = 63.0 dB(A), L_{95} = 60.8 dB(A).

Quiet (Sound condition A). This sound condition was used as a control. The background noise level was about 35 dB(A).

2.4 Questionnaires

A questionnaire with 12 questions was given at the end of each experiment. Each question was followed by a 165 mm long horizontal line, the ends of which were labelled with possible but extreme answers to the question. An example is shown in Figure 2. The questions were answered by marking a cross on the line at the point where the subject felt that his answer could be represented. All positions were allowed. The questions are shown in Table 1 together with the labels of the answering lines. For Questions 1 and 9 a midpoint labelled "neutral" was also given.

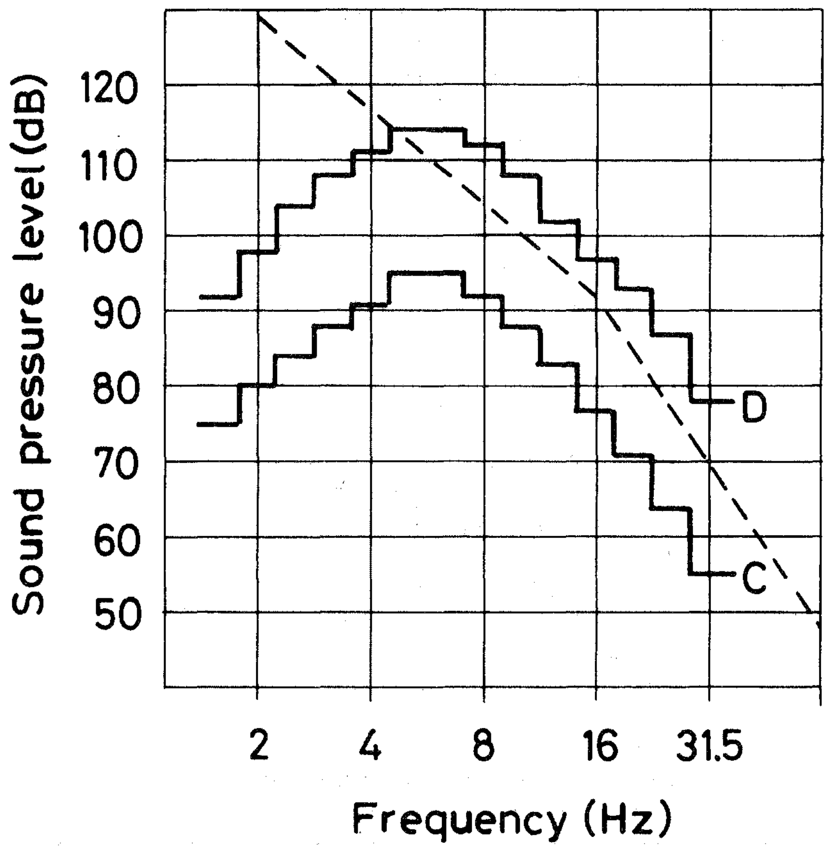

Figure 1 One-third octave analysis of the stimuli C and D. Total sound pressure level: C: 100 dB(lin.), D: 120 dB(lin.). The dotted line shows the threshold curve according to Yeowart *et al.* (Ref. 4). The thresholds are given for pure tones, and levels should not be compared directly with the spectrum levels

Some of the questions concerned the air in the test chamber, and, since the atmospheric conditions were not varied intentionally (see section 2.2), these questions were only included to prevent the subjects from focussing too strongly on possible effects such as headache and dizziness.

The answers to the questions were read as percentages of the length of the answering line taking 0% as the left hand end of line. Answers were scored with a resolution of 5%.

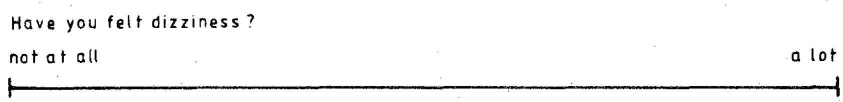

Figure 2 Example of a question with answering line

Table 1 Questions and labels of the corresponding answering lines

1.	How did you find the air? (much too cold – neutral – much too warm)
2.	Have you felt draught? (not at all – a lot)
3.	Have you felt dizziness? (not at all – a lot)
4.	Have the tests been tiring? (not tiring – very tiring)
5.	How did you find the air? (heavy – fresh)
6.	Have you felt nausea? (a lot – not at all)
7.	Have you been annoyed by noise or rumble? (not annoyed – very annoyed)
8.	Have you had a headache? (not at all – severe)
9.	How did you find the air? (dry – neutral – moist)
10.	How have you felt? (dull – fit)
11.	Have you felt pressure on your ears? (a lot – not at all)
12.	Do you find it annoying to sit in a small room like this? (very annoying – not annoying)

2.5 Physiological measurements

The physiological measurements were concerned with the cardiovascular system and the hearing process.

The systolic and diastolic blood pressures were measured with the normal arm-cuff method. The measurement was carried out at fixed times during each experiment, as described in section 2.8.

The electrocardiogram was recorded on tape for certain fixed periods during each experiment. From each of these periods the interbeat-interval T was measured for 126 heartbeats – corresponding to approximately two minutes. The mean of these 126 values of T was taken as representative of the interbeat-interval and it was recorded in milliseconds. The change in T from beat to beat, ΔT, was also recorded for the same 126 heartbeats. Since no change in activity took place during the two minutes measurement period, ΔT would have a mean close to zero. The standard deviation of ΔT was therefore recorded as a measure of the minor variations of the interbeat-interval and it was denoted interbeat-variation.

A phonocardiogram was recorded during the same periods as the electrocardiogram by means of a small microphone attached to the skin at the 4th or 5th intercostal space.

An audiogram covering the seven octave frequencies from 125 Hz to 8 kHz was taken before and after each experiment. A Madsen type OB 40 audiometer was used, and at each frequency the hearing level was measured with a resolution of 5 dB. The hearing level was averaged over the seven frequencies to obtain the mean hearing level, MHL. The influence of an experiment was calculated as $\Delta MHL = MHL(after) - MHL(before)$.

2.6 Task performance

Nine different tests were used. The tasks were presented either on a small film viewer or on a CRT-display terminal. Answers were given by pressing buttons. Some of the tests were developed at The Laboratory of Heating and Air Conditioning at The Technical University of Denmark, where they were used for measuring task performance during exposure to various conditions of temperature, humidity of the air etc. (Ref. 11). All the tests were self-timed in that the answering of one task was immediately followed by the presentation of the next.

Test 1: Five three-digit numbers were presented together with three possible values for the sum. The subject was asked to point out the correct sum or indicate that none of them was correct. The four possible answers were equally probable.

Test 2: Nine two-digit numbers were presented and the subject was asked to indicate if they were all different. In 34% of the presentations two or more figures were identical.

Test 3: The subject was presented with various logical statements and requested to indicate whether each statement was right or wrong.

Examples:

A precedes B: AB (right)

After A is C: CA (wrong)

C does not follow B: CB (right)

A does not precede B: AB (wrong)

Test 4: This was a cue utilization test, a modified version of the Tsai-Partington test (Ref 12). Encircled letters and numbers were shown and an arrow pointed out one of them. The subject was to indicate whether the next sign could be found, when following the order 1-A-2-B-3-C-4-D etc. An example is given in Figure 3.

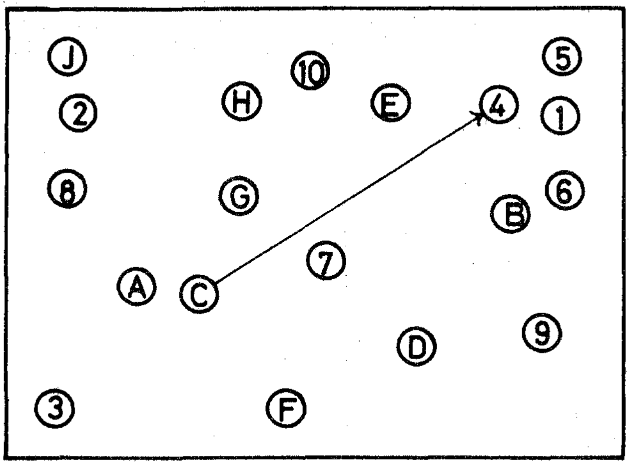

Figure 3 Example of Test 4. The arrow points out "4", and the next character "D" can be found

Test 5: This was a test of short-term memory. A list of words was presented, one word at a time. Each word might occur more than once and as each word was presented the subject was asked to indicate whether he had seen it before.

Test 6: This was a simple reaction time measurement. When a letter appeared in the centre of the CRT-display, a button was to be pressed. The time from an answer to presentation of the next stimulus was random and uniformly distributed in the range 2-6 seconds.

Test 7: Here the display was divided into five parts and the letter E appeared in one of them every 2 seconds. The subject should only respond when the E appeared in the central part.

Test 8: The display was divided into two parts by a vertical line and the letters E and F appeared one at a time at either the left or the right side. The subject should respond to an F on the left or an E on the right.

Test 9: This was similar to Test 2, but it was carried out with the CRT-display terminal in place of the film viewer used in Test 2.

The time the subjects spent on each of the tests is reported in section 2.8.

The distribution of the response time for a subject in a given test was found to be logarithmic normal rather than simple normal. Log(response time/1 second) was therefore used as the dependent variable and mean values were recorded for each experiment. Percentages of errors were also recorded, except for Test 6, the simple reaction time test.

2.7 Experimental design

The 16 subjects were each exposed to the four sound conditions. The latin square in Table 2 was used to balance out order effects. Two subjects were exposed together and the same two subjects followed each other for the whole experiment. A subject was exposed at the same hour of the day every time.

Table 2 The latin square design used in the experiment

	Day of test			
Subject	1	2	3	4
1-4	A	B	C	D
5-8	B	C	D	A
9-12	C	D	A	B
13-16	D	A	B	C

2.8 Procedure

For each experiment a strict time schedule was followed, (see Figure 4). The first 30 minutes were used for an audiometric test, fixing of electrodes, etc. For the next three hours the subjects were seated in the test chamber and exposed to the sound.

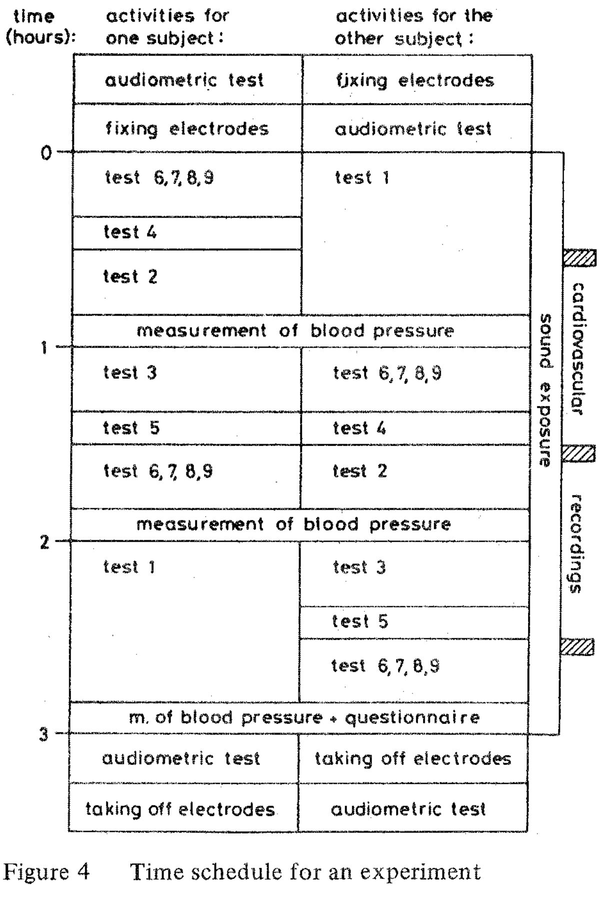

Figure 4 Time schedule for an experiment

During the sound exposure the subjects worked on the performance tests in accordance with the order and times shown in Figure 4. Tests 1-5 were given only once in each experiment, while Tests 6-9 were given twice.

Recordings of the electrocardiogram and phonocardiogram were taken while the subjects worked on the performance tests, the first time after 30 minutes and thereafter with intervals of one hour. Blood pressure was measured after 50 minutes, and at hourly intervals thereafter.

The questionnaire was given just before the end of the exposure to sound. After the exposure had ended, the final audiometric test was given and the electrodes were taken off.

2.9 Data analysis

Mean values were calculated for each dependent variable for each of the four sound conditions. Additionally, a three-way analysis of variance was carried out with the following independent variables: sound (4 conditions), day of test (4 days) and subject (16 subjects). The latin square block design only allowed main effects to be included in the model. An SPSS program package was used for the analysis (Ref. 13).

The cardiovascular variables were measured three times in each experiment. An additional independent variable, the time of measurement (3 times), was included in the model along with the interaction term sound condition by time of measurement.

The phonocardiogram was recorded because earlier studies indicated the occurrence of additional heart sounds during infrasound exposure (not extra sytoles) (Ref. 14). The analysis was confined to listening to the recordings and watching them on an oscilloscope.

3. RESULTS

Mean values for all dependent variables at the four sound conditions are given in Table 3, while the significance levels obtained in the analysis of variance are shown in Table 4.

Table 3 Mean values of the dependent variables for the four sound conditions

	Sound condition			
	A Quiet	B Traffic Noise	C Infrasound "Low"	D Infrasound "High"
Questionnaire:				
Question 1 (%)	50	53	41	40
Question 2 (%)	13	6	16	19
Question 3 (%)	9	21	8	11
Question 4 (%)	51	53	50	59
Question 5 (%)	61	49	64	53
Question 6 (%)	83	90	85	88
Question 7 (%)	10	82	11	70
Question 8 (%)	11	34	12	13
Question 9 (%)	43	46	48	44
Question 10 (%)	46	42	40	29
Question 11 (%)	88	83	93	51
Question 12 (%)	75	78	76	79
Physiological measurements:				
Systolic blood pressure (mm Hg)	120.4	119.4	120.3	120.5
Diastolic blood pressure (mm Hg)	77.6	77.8	75.7	75.8
Interbeat-interval (ms)	802	787	799	808
Interbeat-variation (ms)	47.7	41.8	43.6	43.0
ΔMHL (dB)	−2.8	1.7	−2.7	−2.0
Task performance:				
Test 1: log(response time/1 s)	1.31	1.31	1.31	1.34
errors (%)	11.6	10.4	11.5	9.8
Test 2: log(response time/1 s)	0.71	0.69	0.70	0.71
errors (%)	8.8	8.5	7.4	7.6
Test 3: log(response time/1 s)	0.61	0.58	0.57	0.61
errors (%)	4.1	2.9	3.6	4.1
Test 4: log(response time/1 s)	0.48	0.49	0.49	0.50
errors (%)	2.0	1.9	1.7	3.5
Test 5: log(response time/1 s)	0.16	0.14	0.14	0.16
errors (%)	8.4	7.9	6.9	7.1
Test 6: log(response time/1 s)	−0.57	−0.55	−0.56	−0.56
Test 7: log(response time/1 s)	−0.59	−0.58	−0.59	−0.56
errors (%)	0.4	0.4	0.2	0.5
Test 8: log(response time/1 s)	−0.31	−0.31	−0.32	−0.30
errors (%)	3.2	2.8	2.2	3.0
Test 9: log(response time/1 s)	0.58	0.53	0.56	0.56
errors (%)	6.6	7.3	6.3	8.5

Table 4 Significance levels obtained in the analysis of variance. Only significance at a level of 0.05 or higher is given. Terms not included in the model are indicated with ' – '

	Main effects				Interaction
	Day of test	Subject	Sound condition	Time of measurement	Time of measurement by sound condition
Questionnaire:					
Question 1	0.002	n.s.	0.042	–	–
Question 2	n.s.	<0.001	n.s.	–	–
Question 3	n.s.	<0.001	0.038	–	–
Question 4	0.037	<0.001	n.s.	–	–
Question 5	0.009	<0.001	n.s.	–	–
Question 6	0.042	<0.001	n.s.	–	–
Question 7	n.s.	<0.001	<0.001	–	–
Question 8	n.s.	<0.001	<0.001	–	–
Question 9	n.s.	n.s.	n.s.	–	–
Question 10	n.s.	<0.001	n.s.	–	–
Question 11	n.s.	<0.001	<0.001	–	–
Question 12	n.s.	<0.001	n.s.	–	–
Physiological measurements:					
Systolic blood pressure	0.002	<0.001	n.s.	0.025	n.s.
Diastolic blood pressure	<0.001	<0.001	n.s.	<0.001	n.s.
Interbeat-interval	n.s.	<0.001	n.s.	<0.001	n.s.
Interbeat-variation	n.s.	<0.001	n.s.	<0.001	n.s.
ΔMHL (dB)	n.s.	n.s.	0.006	–	–
Task performance:					
Test 1: log(response time/1 s)	n.s.	<0.001	n.s.	–	–
errors	<0.001	<0.001	n.s.	–	–
Test 2: log(response time/1 s)	<0.001	<0.001	n.s.	–	–
errors	0.033	<0.001	n.s.	–	–
Test 3: log(response time/1 s)	<0.001	<0.001	n.s.	–	–
errors	0.003	<0.001	n.s.	–	–
Test 4: log(response time/1 s)	<0.001	<0.001	n.s.	–	–
errors	n.s.	n.s.	0.016	–	–
Test 5: log(response time/1 s)	0.010	<0.001	n.s.	–	–
errors	n.s.	<0.001	n.s.	–	–
Test 6: log(response time/1 s)	n.s.	<0.001	n.s.	–	–
Test 7: log(response time/1 s)	n.s.	<0.001	n.s.	–	–
errors	n.s.	<0.001	n.s.	–	–
Test 8: log(response time/1 s)	n.s.	<0.001	n.s.	–	–
errors	n.s.	n.s.	n.s.	–	–
Test 9: log(response time/1 s)	<0.001	<0.001	n.s.	–	–
errors	n.s.	<0.001	n.s.	–	–

Figures 5, 7 and 10 illustrate dependence on sound conditions, while variation with treatment day is shown in Figures 6, 8 and 11. Figure 9 shows dependence on time of measurement for the cardiovascular parameters.

In the phonocardiogram there were no unusual observations such as extra sounds.

4. DISCUSSION

4.1 Questionnaires

Effects of sound conditions. For Questions 1, 3, 7, 8 and 11, there are significant effects of sound conditions. This is illustrated in Figure 5.

Question 1 concerns the temperature of the room. It is seen from Figure 5 that the air is perceived as being colder during infrasound exposure compared with the other conditions. The effect is surprising. A possible explanation is that the motion of the air due to the sound increases the convective heat transport from the body to the air. A rough estimate of the air velocity is 0.1-0.2 m/s rms near the loudspeakers at sound condition D. The possibility cannot be excluded that this motion of the air makes it feel colder, but because of the small difference between condition C and D, and taking into account the low significance level, the effect is believed to be a type 1 error.

Question 3 deals with dizziness. From Figure 5 it can be seen that a slightly higher degree of dizziness is obtained at sound condition B than at A, C or D. Thus the traffic noise causes higher ratings of dizziness than either of the infrasound conditions and the quiet condition.

The annoyance arising from noise or rumble is judged in Question 7. It is obvious that the ratings of conditions A and C are very low and approximately the same, while both B and D produce high values. This means that the subjects are very annoyed by the traffic noise and by the audible infrasound. Ratings for A and C are not exactly zero, probably due to noise from other activities in the building.

Question 8 deals with headache. Some headache is experienced in all sound conditions, but the rating for sound condition B is clearly higher than for the other conditions. Thus traffic noise results in an increased occurrence of headache, while infrasound, audible or inaudible, does not.

A feeling of pressure on the ears (Qeustion 11) is reported in sound condition D (note that the labelling of the answering line is reversed in this question). It is not clear whether this feeling is caused by a real middle ear pressure build-up, or that the subjects simply express their perception of infrasound in this way. An improved wording of the question should be considered for future investigations.

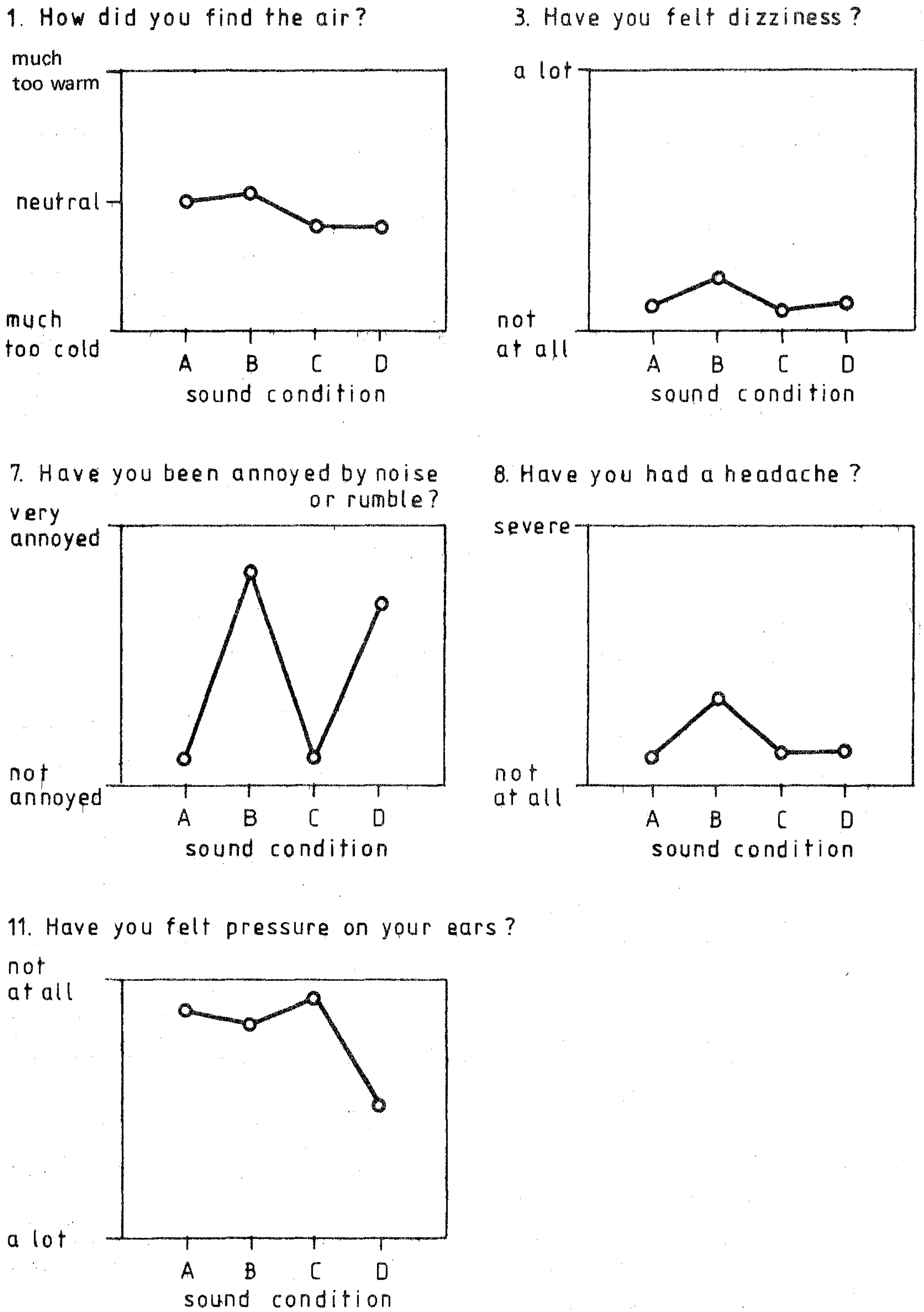

Figure 5 Questions 1, 3, 7, 8 and 11; means for the four sound conditions. Significance levels: Question 1: 0.042; Question 3: 0.038; Question 7: <0.001; Question 8: <0.001; Question 11: <0.001

Effects of day of test. A significant effect of 'day of test' is found for Questions 1, 4, 5 and 6. This is illustrated in Figure 6.

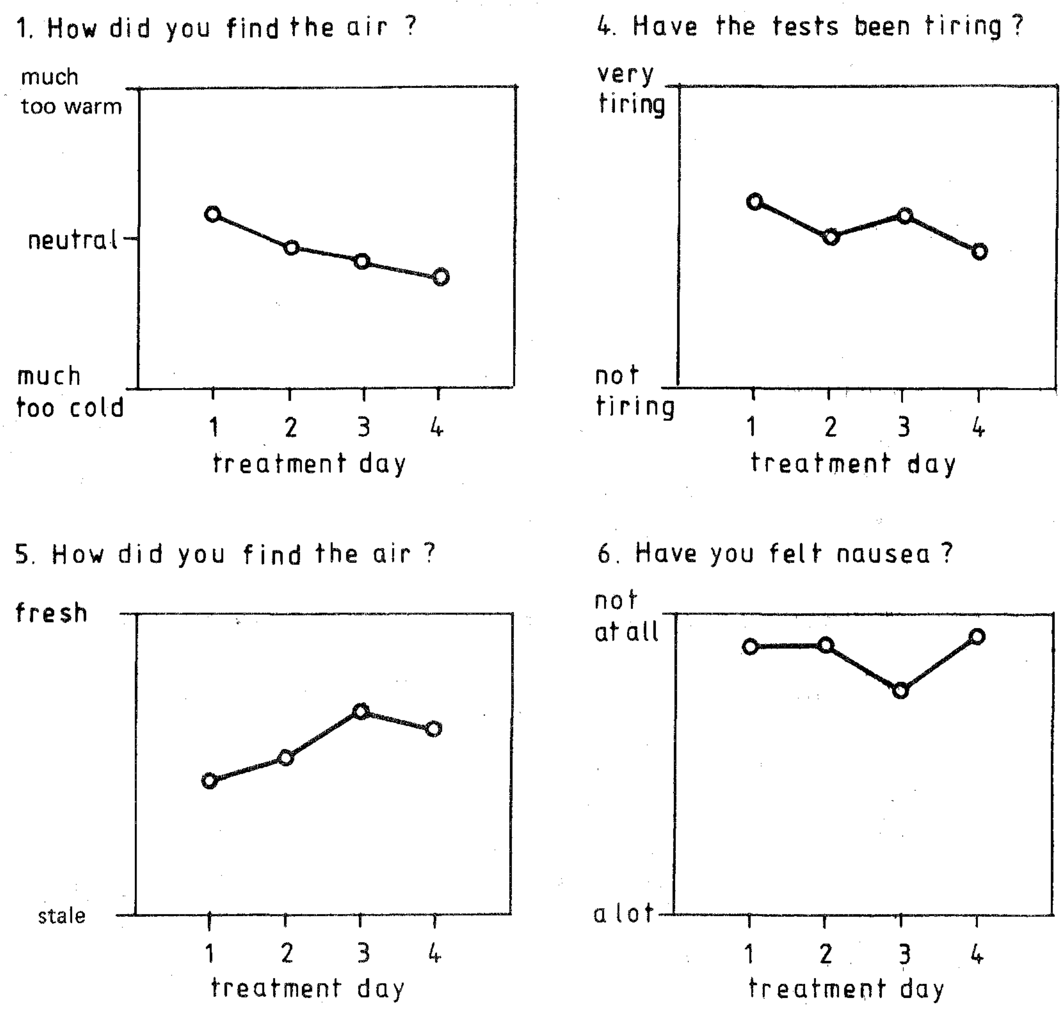

Figure 6 Questions 1, 4, 5 and 6; means on the four days of test. Significance levels: Question 1: 0.002; Question 4: 0.037; Question 5: 0.009; Question 6: 0.042

Questions 1 and 5 concern the air in the room, which is perceived as colder and fresher on the first occasion on which a subject participates compared with his fourth and last participation. The physical fluctuations in air temperature, humidity of the air and atmospheric pressure were small, and there was no general trend from the beginning to the end of the experimental period. This does not appear to be a chance effect, considering the significance levels and the agreement between the answers to the two questions. The change in perception can be explained as an adaptation effect.

Results from Question 4 "Have the tests been tiring?" show a generally falling tendency with time. In particular, ratings from the last day are lower than from the others. A possible explanation is that the tests become more acceptable towards the end of the experiment, especially on the last day.

Question 6 is "Have you felt nausea?" and the results indicate an increased feeling of nausea when the subjects participate for the third time. The significance level is only 0.042 and no reasonable explanation of the phenomenon can be given.

4.2 Physiological measurements

Effects of sound conditions. The only parameter that is significantly influenced by sound conditions is ΔMHL (the change in mean hearing level). The dependence is shown in Figure 7.

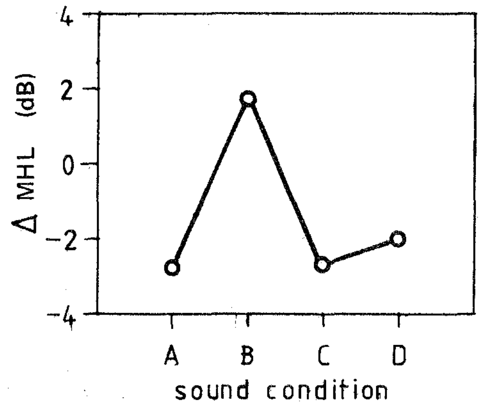

Figure 7 ΔMHL; means on the four sound conditions. Significance level: 0.006

The value of ΔMHL is approximately 4 dB higher for B than for the other sound conditions, indicating that the traffic noise introduces a temporary threshold shift (TTS). A detailed analysis has shown that the TTS is broadband.

It is also seen that the values at sound conditions A, C and D are negative. This means that the hearing of the subjects becomes better during the experiments A, C and D. An explanation may be that the subjects arrive for the experiments with a minor TTS which might, for example, have been caused by traffic noise on their way to the laboratory.

Effects of day of test. Systolic and diastolic blood pressure are significantly dependent on day of test, and higher values are found on the first day, see Figure 8.

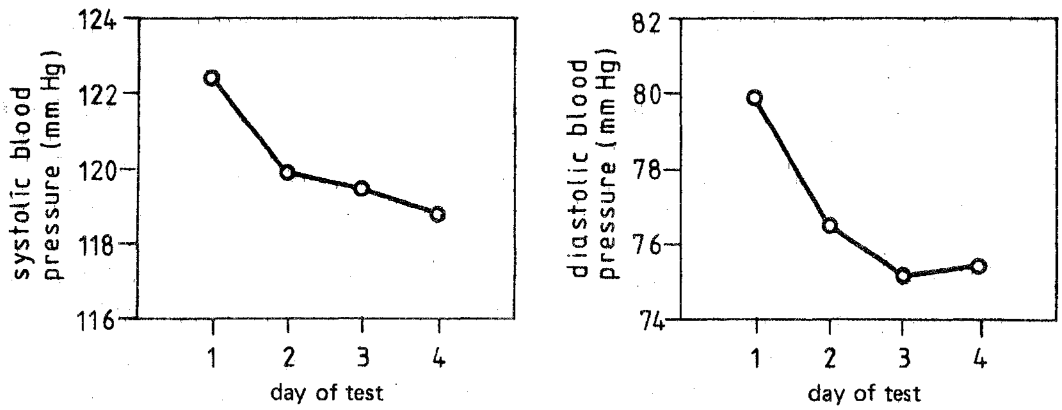

Figure 8 Systolic and diastolic blood pressure; means on the four treatment days. Significance levels: systolic blood pressure: 0.002; diastolic blood pressure: <0.001

Effects of time of measurement. All cardiovascular parameters are dependent on the time of measurement. Figure 9 shows that at the beginning of the experiment the blood pressures are lower, the pulse faster, and the interbeat-variation lower than for the rest of the experiment.

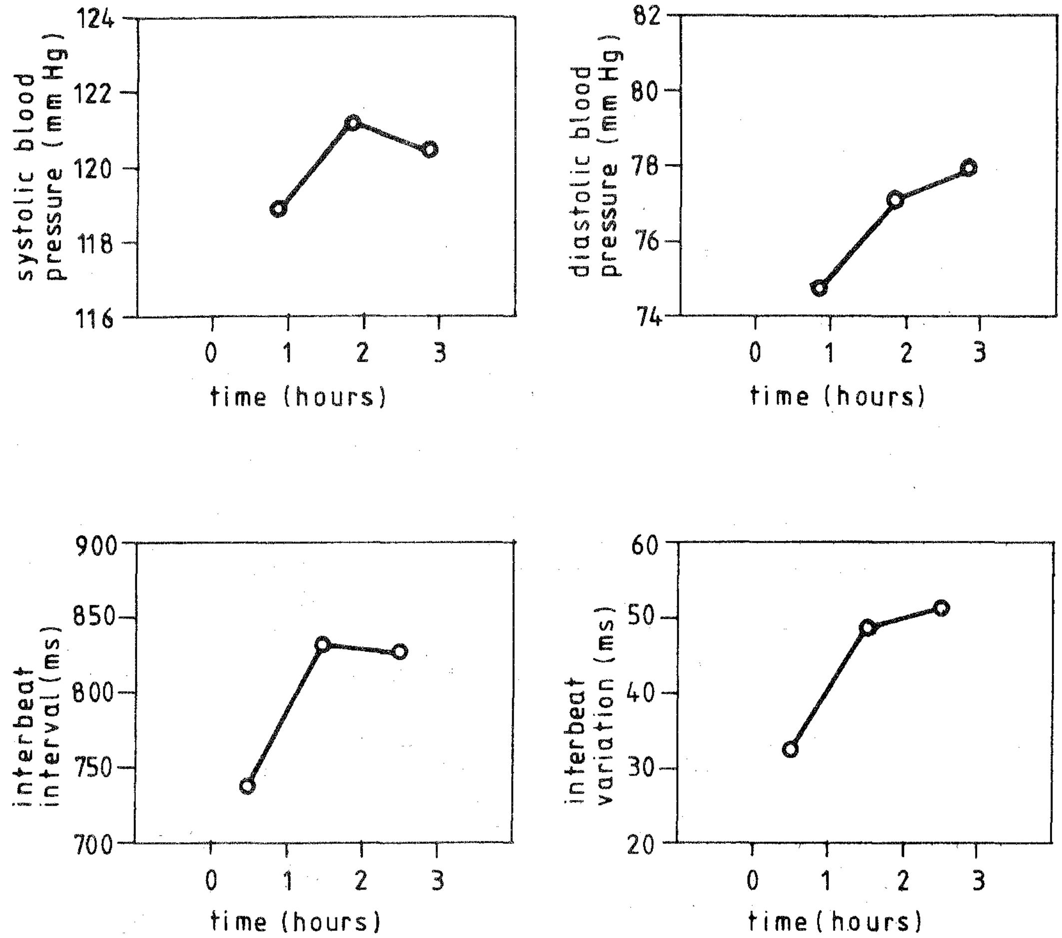

Figure 9 Cardiovascular parameters; means at different times of measurement. Significance levels: systolic blood pressure: 0.025; diastolic blood pressure: <0.001; interbeat-interval: <0.001; interbeat-variation: <0.001

Effects of day of test and time of measurement are believed to be psycho-physiological and caused by the participation of the subjects in a scientific experiment.

4.3 Task performance

Effects of sound condition. The only test in which errors were found to be significantly dependent on sound condition was test 4. Figure 10 clearly illustrates that there are more errors at sound condition D (audible infrasound).

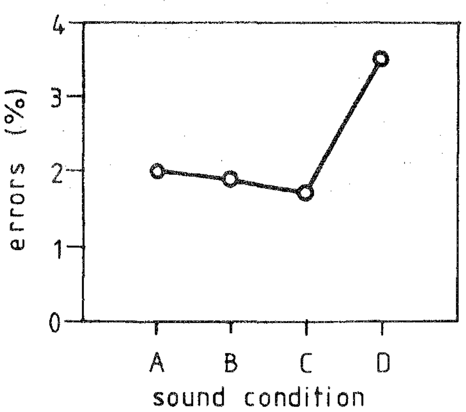

Figure 10 Errors in Test 4; means for the four sound conditions. Significance level 0.016

Effects of day of test. Many variables are significantly influenced by day of test as shown in Figure 11. It is obvious that the response time decreases with time. The average improvement in log(response time/1 s) from the first to the fourth time a subject participates is 0.114, which corresponds to a decrease in response time of 23%.

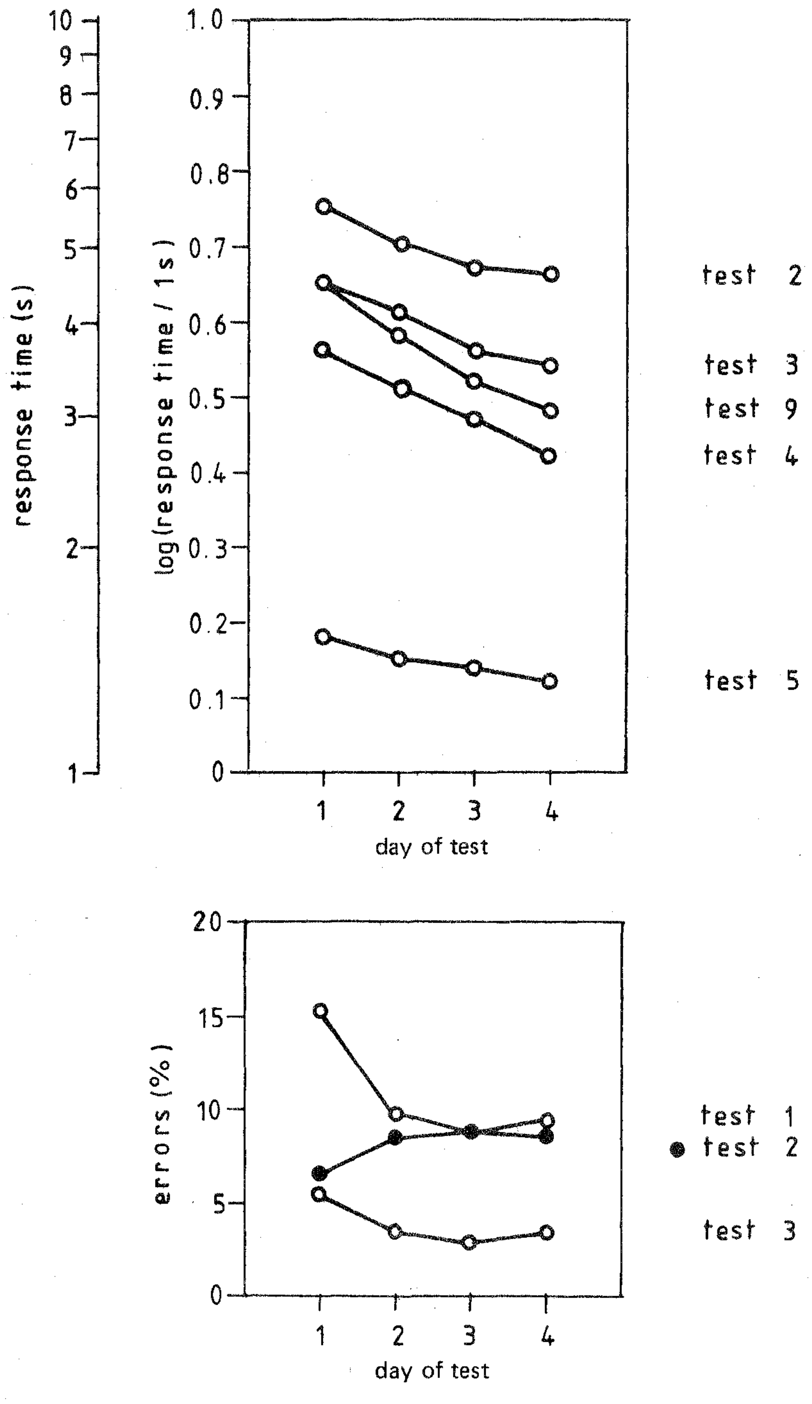

Figure 11 Response time in Tests 2, 3, 4, 5 and 9, and errors in Tests 1, 2 and 3; means on the four treatment days. Significance levels: response time: Test 2: <0.001; Test 3: <0.001; Test 4: <0.001; Test 5: 0.010; Test 9: <0.001; errors: Test 1: <0.001; Test 2: 0.033; Test 3: 0.003

For Tests 1 and 3 an improvement in performance is seen as the number of errors decreased with time, however in Test 2 an increase in errors is seen. This increase may be chance (the significance level is only 0.033), or it may indicate that the subjects change their priority from accuracy to speed as the experiment proceeds.

4.4 General

For most of the dependent variables no effects of infrasound are found. None of the cardiovascular parameters are significantly influenced by the infrasound and a significant deterioration of task performance is seen in only one test. The questionnaires show that no sensations of dizziness, tiredness, nausea or headache are introduced by the infrasound.

The lack of significant effects due to infrasound is in contrast to a number of reports (Refs. 9, 10, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31) but in agreement with several others (Refs. 32, 33, 34, 35, 36). It is not the purpose of this paper to present a review of the literature, but the author would draw attention to the fact that most of the papers that mention severe extra-auditory effects of infrasound are survey papers. It is the opinion of the author that many of these can be criticised for their generalisations from the sporadic and unsystematic findings of other authors. When effects are summarized, the original reservations are often forgotten and non-significant tendencies easily change into facts.

Much confusion is caused by misconceptions about the audibility of infrasound. It is not generally known that infrasound can be detected by the human ear. Therefore, true effects of audible, and possibly loud, infrasound are often reported as being caused by "inaudible infrasound".

When a dependent variable in an experiment does not appear to be dependent on the independent variable there may be a true lack of dependence, or the choice of design and statistical analysis may be inadequate. In this connection, it should be noticed that only main effects have been considered in the present investigation. If some subjects are especially sensitive to infrasound, this will appear in the analysis as an interaction effect between subject and sound condition. In the present design where the subjects are exposed to each sound condition only once, this interaction cannot be tested. If such an interaction exists, it may even reduce the power of the test to reveal main effects because the error variance will be estimated to be too large. A look at the significant main effects found for other variables (Figures 6, 8, 9, 11) may give an idea of the magnitude of the effects that could be detected in the present experiment.

5. CONCLUSION

Infrasound slightly above the hearing threshold gave a feeling of pressure on the ear and it was given a high rating on an annoyance scale. The infrasound did not cause headache, nausea, tiredness or dizziness, and did not influence the circulatory system. The subjects performance differed significantly from the control in only one of nine tests. No effects were observed for infrasound below threshold.

In the literature, extra-auditory effects seem to have been exaggerated while effects related to hearing may have been underestimated. Therefore, a better knowledge is required of the hearing function at infrasonic frequencies. In particular, the fact that infrasound less than 20 dB above the hearing threshold was rated close to "very annoying" emphasises the need for curves of equal annoyance.

The hearing threshold curve has already been determined with reasonable accuracy (Refs. 1, 2, 3, 4, 5) and some preliminary curves of equal loudness have been given (Refs. 3, 37, 38, 39). Some introductory approaches to a frequency dependent limit based on a discomfort criterion have also been made (Refs. 5, 40) and at the Institute of Electronic Systems, experiments are being carried out to determine a complete set of equal annoyance curves (Refs. 41, 42).

The exposure levels used in this investigation are somewhat below the maximum levels found in industry and transportation and additional experiments need to be carried out at slightly higher levels. The validity of the results for older age groups should also be investigated.

The performance tests used in this investigation were all relatively simple, and cannot be compared to demands that are made on, for example, bus or lorry drivers. Recent research has shown that mainly complex tasks – for example simultaneous work on two or more tasks – are influenced by ordinary noise (Refs. 43, 44). In the experiment reported here, no effect was seen even from traffic noise and future investigations ought to clarify whether the absence of effects is also found for more realistic and complex tasks.

ACKNOWLEDGEMENTS

The author wishes to thank the following persons for their assistance and advice: Jørgen Bach Andersen Dr. techn., Jente Andresen cand. psych., Bjarne Kirk B. Sc., Gunnar Langkilde M. Sc., Anders Bungard Mortensen B. Sc., Per Rubak M. Sc.

Financial support from Aalborg University and The Siemens Foundation is also gratefully acknowledged.

REFERENCES

1. **G. von Békésy.** *Über die Hörschwelle und Fühlgrenze langsamer sinusförmiger Luftdruckschwankungen. Annalen der Physik, 5. Folge, Band 26, 554-566, 1936.*

2. **N.S. Yeowart, M.E. Bryan and W. Tempest.** *The monaural M.A.P. threshold of hearing at frequencies from 1.5 to 100 c/s. J. Sound Vib., Vol.6, 335-342, 1967.*

3. **L.D. Whittle, S.J. Collins and D.W. Robinson.** *The audibility of low frequency sounds. J. Sound Vib., Vol.21, 431-448, 1972.*

4. **N.S. Yeowart and Margaret J. Evans.** *Thresholds of audibility for very low-frequency pure tones. J. Acoust. Soc. Am., Vol.55, 814-818, 1974.*

5. **S. Yamada, T. Kosaka, K. Bunya, T. Amemiya.** *Hearing of low frequency sound and influence on human body. In Henrik Møller and Per Rubak (Eds.): Proceedings of Conference on Low Frequency Noise and Hearing, 7-9 May 1980 Aalborg, 95-102, 1980.*

6. **H. Møller.** *The influence of infrasound on task performance. In Henrik Møller and Per Rubak (Eds.): Proceedings of Conference on Low Frequency Noise and Hearing, 7-9 May 1980 Aalborg, 85-94, 1980.*

7. **H. Møller.** *Effects of infrasound on man. Internoise 81, Amsterdam, 6-8 October, 747-750, 1981.*

8. **H. Møller.** *Construction of a test chamber for human infrasound exposure. J. Low Frequency Noise and Vibration, Vol.1, 123-134, 1982.*

9. **V. Gavreau, R. Condat, H. Saul.** *Infra-sons: Générateurs, Détecteurs, Propriétés physique, Effets biologiques. Acustica, Vol.17, 1-10, 1966.*

10. **P.V. Brüel and H.P. Olesen.** *Infrasonic measurements. Internoise 73, Copenhagen, 22-24 August, 599-603, 1973.*

11. **G. Langkilde.** *The influence of the thermal environment on office work. In P.O. Fanger and O. Valbjørn (Eds.): Indoor Climate. Danish Building Research Institute, Copenhage, 835-856, 1979.*

12. **C.H. Ammons.** *Tasks for the study of perceptual learning and performance variables. Percept. Mot. Skill, Vol.5, 11-14, 1975.*

13. **N.H. Nie, C.H. Hull, J.G. Jenkins, K. Steinbrenner, D.H. Bent.** *SPSS, Statistical Package for the Social Sciences. 2nd ed. McGraw-Hill, New York, 1975.*

14. **P. Grognot.** *Reaction physiopathologiques de l'etre humain expose a des infra-sons appliques par voie auriculaire. Journees Francaises d'Environment, Ecole Nationale Superieure de l'Aeronatique, Paris, 31 Mars-1 Avril, 83-91, 1969.*

15. **J.E. Green and F. Dunn.** *Correlation of naturally occurring infrasonics and selected human behaviour. J. Acoust. Soc. Am., Vol.44, 1456-1457, 1968.*

16. **M. Miles.** *Can't concentrate – it might be infrasound. Los Angeles Times, 20 September, 1970.*

17. **E.Z. Andreeva-Galanina.** *Effects of infrasound on the human system. Gigiena i Sanitariya, Vol.11, 65-69, 1970.*

18. **R.A. Hood, H.G. Leventhall and K. Kyriakides.** *Some subjective effects of infrasound. British Acoustical Society Meeting on Infrasound and Low Frequency Vibration, 26th November, University of Salford, 1971.*

19. **R. Fecci, R. Barthelemy, J. Bourgoin, A. Mathias, H. Eberle, A. Moutel.** *L'action des infra-sons sur l'organisme. Medicine del Lavoro, Vol.62, 130-150, 1971.*

20. **M. Bryan, W. Tempest.** *Does infrasound make drivers drunk? New Scientist, 584-586, 16 March, 1972.*

21. **Margaret J. Evans, W. Tempest.** *Some effects of infrasonic noise in transportation. J. Sound Vib., Vol.22, 19-24, 1972.*

22. **H.G. Leventhall.** *Man-made infrasound – it's occurrence and some subjective effects. In L. Pimonow (Ed.): Proceedings of Colloque International sur les Infra-sons, Paris, 24-27 September, 129-152, 1973.*

23. **R.A. Hood.** *The occurrence and some subjective effects of infrasonic noise. Ph. D. Thesis, University of London, 1973.*

24. **P. Bonnevie.** *Lavfrekvente "uhφrlige lyde". Ugeskrift for laeger, Vol.136, 1223-1224, 27 May 1974.*

25. **S. Händel, P. Jansson.** *Infraljudet – förekomst och verkningar. Läkartidningen, Vol.71, 1635-1639, 1974.*

26. **N.R. Dotti.** *Infrasonics: Unheard noises affecting man. Pollution Engineering, Vol.8, 36-39, 1976.*

27. **L. Liszka, Ing-Marie Lidström.** *Infraljud i arbetsmiljön. Arbetarskyddsnämnden, Sweden, 1976.*

28. **S. Alm, J. Hellström, N-G. Henrikson, B. Johanson, L. Liszka, A. Mφller, L.O. Strahle, H. Westling.** *Infraljud och dess paverkan pa människan. Ingenjörsvetenskapsakademien, meddelande 208, Stockholm 1977.*

29. **H. Ising, C. Wittke.** *Long-term exposure of working persons to low frequency noise. Institute of Acoustics Meeting on Low Frequency Noise, Chelsea College, London, 5th January 1979.*

30. **O. Okai, M. Saito, M. Taki, A. Mochizuchi, N. Nishiwaki, T. Mori, N. Fujio.** *Physiological parameters in human response to infrasound. In Henrik Mφller and Per Rubak (Eds.): Proceedings of Conference on Low Frequency Noise and Hearing, 7-9 May 1980, Aalborg, 121-129, 1980.*

31. **H. Ising.** *Psychological, ergonomical and physiological effects of long-term exposure to infrasound and audiosound. In Henrik Mφller and Per Rubak (Eds.): Proceedings of Conference on Low Frequency Noise and Hearing, 7-9 May Aalborg, 77-84, 1980.*

32. **G.C. Mohr, J.N. Cole, Elizabeth Guild, H.E. von Gierke.** *Effects of low frequency and infrasonic noise on man. Aerospace Medicine, Vol.36, No.9, 817-824, 1965.*

33. **B.R. Alford, J.F. Jerger, A.C. Coats, J. Billingham, B.O. French, R.O. McBrayer.** *Human tolerance to low frequency sound. Trans. Am. Acad. Ophth. Otolaryng., Vol.70, 40-47, 1966.*

34. **H.E. von Gierke, D.E. Parker.** *Infrasound. In W.D. Keidel, W.D. Neff: Handbook of Sensory Physiology, Vol.V: Auditory System, Part 3: Clinical and Special Topics, Springer Verlag, 585-624, 1976.*

35. **C.S. Harris, H.C. Sommer, D.L. Johnson.** *Review of the effects of infrasound on man. Aviation, Space and Environmental Medicine, Vol.47, 430-434, 1976.*

36. **C.S. Harris, D.L. Johnson.** *Effects of infrasound on cognitive performance. Aviation, Space and Environmental Medicine, Vol.49, 582-586, 1978.*

37. **B. Kirk, H. Mφller.** *Loudness and annoyance of infrasound. Internoise 81, Amsterdam, 6-8 October, 761-764, 1981.*

38. **H. Mφller, J. Andresen.** *Loudness of infrasound. Internoise 83, Edinburgh, 13-15 July, 815-818, 1983.*

39. **H. Mφller, J. Andresen.** *Loudness of pure tones at low and infrasonic frequencies. Submitted to Journal of Low Frequency Noise and Vibration.*

40. **D. Augustyńska, W. Szelenberger.** *A cabin for investigating the influence of infrasound on man. (In Polish). The XXVI Open Seminar on Acoustics, Wroclaw-Olesnica, 1979.*

41. **J. Andresen, H. Møller.** *Annoyance of infrasound. Internoise 83, Edinburgh, 13-15 July, 819-822, 1983.*

42. **J. Andresen, H. Møller.** *Equal annoyance contours for infrasonic frequencies. Submitted to Journal of Low Frequency Noise and Vibration.*

43. **S. Cohen, N. Weinstein.** *Nonauditory effects of noise on behaviour and health. Journal of Social Issues, Vol.37, 36-70, 1981.*

44. **P.A. Bell.** *Effects of noise and heat stress on primary and subsidiary task performance. Human Factors, Vol.20, 749-752, 1978.*